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Refrigerant options **now** and in the **future**

A white paper on the global trends within refrigerants in air conditioning and refrigeration seen from a Danfoss perspective.

Achieving sustainable HVAC/R through intelligent solutions, energy efficiency and

low GWP

refrigerants

www.refrigerants.danfoss.com

Policy Statement

Danfoss encourages the further development and use of low GWP refrigerants to help slow, and ultimately reverse, the process of global warming while helping to ensure continued global well being and economic development along with the future viability of our industry.

We will enable our customers to achieve these refrigerant goals while continuing to enhance the energy efficiency of refrigeration and air-conditioning equipment.

Danfoss will proactively develop products for low-GWP refrigerants, both natural and synthetic, to fulfil customers' needs for practical and safe solutions without compromising energy efficiency.

Danfoss will lead and be recognized in the development of natural refrigerant solutions.
Danfoss will develop and support products for low GWP synthetic refrigerants, particularly for those applications where natural refrigerant solutions are not yet practical or economically feasible.

Danfoss supports the establishment of a global regimen through the Montreal Protocol to phase down emissions of high GWP refrigerants.

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Executive Summary

Danfoss, world leader in the supply of compressors and controls to the refrigeration and air conditioning industry, has a product range that is among the most complete worldwide. Our products are found within a number of business areas, such as food retail, commercial and industrial refrigeration and air conditioning, products for the wholesale refrigeration market and automation in various specific industrial sectors. More than eight decades of experience has made Danfoss the leader in developing products using refrigerants and evaluating the viability of new refrigerants.

This paper contains a condensed look at our experience and knowledge, describing the background, the trends, and drivers that frame the scenarios for present and future refrigerant selection. While selecting new alternatives implies investments, costs and burdens, we strongly believe that if these selections are made correctly it can open doors to new opportunities; these include combining heating and cooling systems, which is becoming a very efficient driver for CO_2 reduction technologies.

The history of refrigerants is a long and cyclic story. We believe that vapor compression systems will remain the primary technology for the foreseeable future. It is anticipated that refrigerant consumption will grow strongly following the increasing demand from emerging economies. Selection of the systems and technologies while using the best refrigerant is a trade-off between several factors and will impact the system users for a long time. Safety, affordability and environment are the three main elements to consider. The balance of these three factors is rarely found only targeting one refrigerant. Instead, to achieve lower GWP solutions it is necessary to take new energy systems and regional competence development into account.

While developing new safe technologies and procedures for handling systems, our perception of refrigerant use will also move towards much lower GWP refrigerants than we see today. We foresee a decade of complex development and hopefully a global agreement on an orderly phase-down of high GWP refrigerants.

History

One hundred eighty years have passed since Jacob Perkins patented the vapor compression cycle, which also launched the history of refrigerants. The vapor compression cycle uses the refrigerant to transport heat from the cold side to the hot side of a refrigeration system, heat pump, or air conditioning system. We, essentially, use the same thermodynamic cycle today, however, the refrigerants have changed throughout time.

Figure 1 shows the development of refrigerants through the last one hundred eighty years. In the beginning all refrigerants were, by definition, environmentally friendly as they could be found in nature, nevertheless in the thirties, it became obvious that there were critical safety issues involving many of these refrigerants. There were cases of fires and poisonings caused by leakage of these refrigerants. At this time, synthetic safety refrigerants called CFCs were invented and were widely used on a global scale. , Partly chlorinated refrigerants (HCFC), including R22, were introduced during the fifties.

In the early seventies, it was discovered that CFC and HCFC refrigerants breakdown the ozone layer. CFCs have a particularly high Ozone Depleting Potential (ODP) while HCFCs are comparatively modest. As a consequence the Montreal Protocol – a phase-down mechanism on Substances that Deplete the Ozone Layer- was established and has since been regarded as a real global success on reducing dangerous chemical substances. In addition to reducing the ODP load in the atmosphere, the reduction of CFC emissions has also decreased the global warming impact considerably. The substitute refrigerants, called HFCs, have zero ODP but unfortunately medium to high Global Warming Potentials (GWP) even though they are considerably lower than the phased-out CFCs. Due to the threat of climate change, usage of HFCs is now being scrutinized in an attempt to reduce their impact on the environment. Scientific investigations show that while the impact of HFC leakages may not currently be a major contributor to global warming, their growing consumption, especially within air conditioning units in developing countries, will eventually make the HFCs a top contributor if no reducing measures are introduced. The question on how to phase out high GWP HFCs with low GWP alternatives is the subject of an ongoing process and debate. This has already led to the reintroduction of natural refrigerants and to the development of low GWP synthetic refrigerants; however, it remains a measure that requires further development .

In summary, if not handled properly, refrigerants may cause severe short or long-term environmental consequences. History has been a learning curve away from the flammable and toxic refrigerants towards safe solutions but which are not sustainable in the long term. Technological developments, together with safety standardization, have finally made it possible to begin moving towards real long-term solutions with zero ODP and low GWP refrigerants. At the same time energy efficiency measures have been developed to decrease indirect emissions.

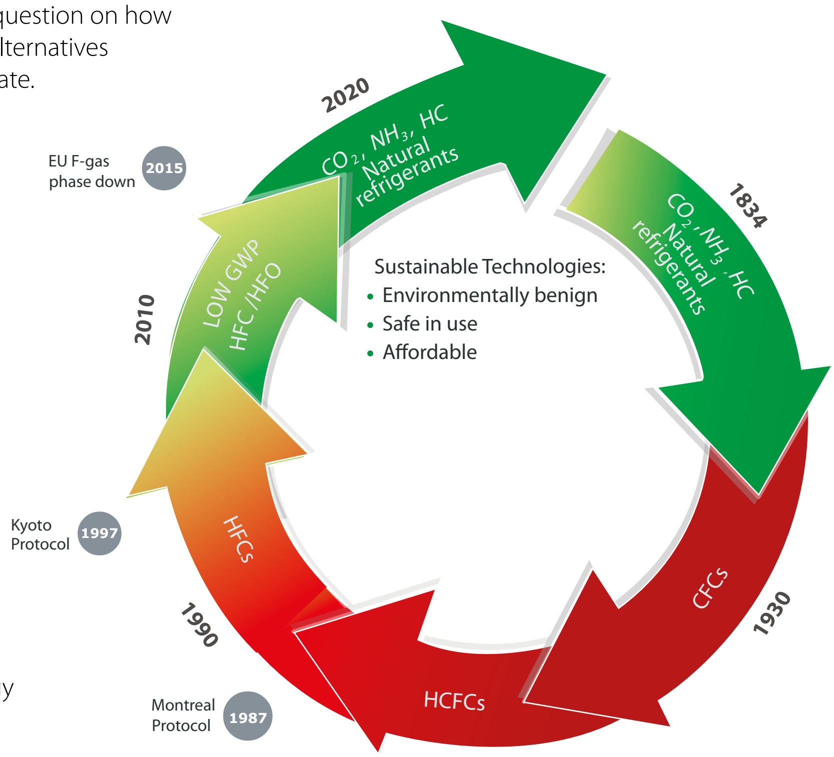


Figure 1: The historical cycle of refrigerants

Sustainability is the Key

Sustainable solutions are in the best interests of all stakeholders in our industry. Sustainability safeguards long-term investments and ensures compliance with Corporate Social Responsibility (CSR). In retrospect it is clear that the refrigerant choices made in the past were not sustainable and as a result society and industries needed to reconsider and reinvest. Today when talking about refrigerants and long-term sustainability, Danfoss considers three main parameters that must be aligned to accomplish a real sustainable balance: affordability, safety and environment.

When choosing a new refrigerant for an application all three parameters have to be considered simultaneously. If only one parameter is optimized it will not be possible to achieve a sustainable result. It is important to look at parameters such as; lowest life cycle cost of the system, service availability and safe operation, and of course, the global warming potential of the refrigerant. A sustainable solution will be achieved only when all these parameters are in balance. Creating this balance requires thorough evaluation and consideration of regional differences which influence these parameters as shown in Figure 2.

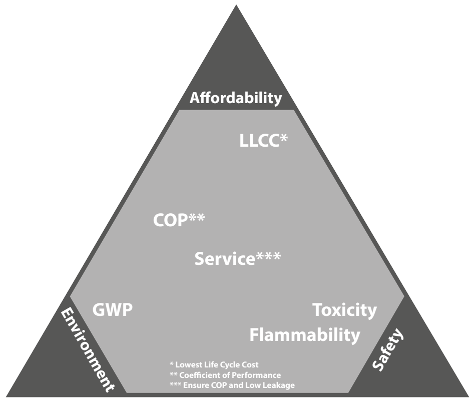
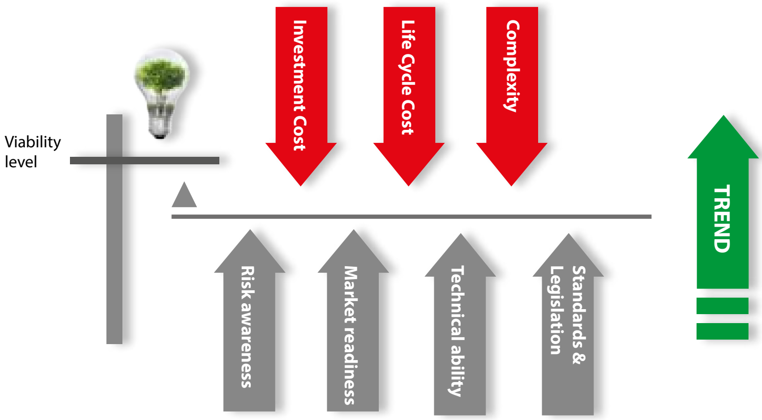


Figure 2: Refrigerant Sustainability Triangle

While sustainable outlooks seem clear, there are more factors triggering industrial development and investments. To quantify the industrial viability of developing new sustainable solutions for specific refrigerants, Danfoss has developed a model that breaks down the main parameters.

We call this the 7 Force model and it is illustrated in Figure 3. The red arrows refer to economics and the grey arrows relate to knowledge, education and legislation. When the balance between the red and grey forces reaches the viability level there is a high potential for the industry to invest in new solutions. When investing in new technology and competence build up, legislation and derived standardization are the major drivers.
The viability level has been increasing for many low GWP refrigerants during the last ten years. Good examples are CO2 emissions for commercial refrigeration, especially supermarkets, and hydrocarbons for low charged vending machines.



1.	Investment cost	Investments in Product development
2.	Life cycle cost	Life cycle cost for the consumer. Contains up front cost and running cost
3.	Complexity	Complexity associated with manufacturing and marketing of the product
4.	Risk Awareness	Difference between perceived and actual risk using the product
5.	Market Readiness	Market competence in save adoption of new technologies and products
6.	Technical Ability	Ability and competence in developing new products
7.	Standard & Legislation	S&L includes bans taxes and voluntary agreements.

Figure 3: The Seven Forces model

Regulation

Regulatory certainty is one of the most important parameters for spurring investment in new technology. Figure 4 charts an overview of phase-outs and phase-downs that have already been imposed on the industry, and also some possible projections into the future. The phase-out of HCFC, mainly R22, has already been accomplished in the EU and is close to being finalized in US and other developed countries. The developing countries began phasing out HCFC in 2015 and will continue until 2030. It is important to remember that HCFC R22 is a refrigerant used in many different applications, which makes achieving compliance a challenge as no single refrigerant can replace it.

For the last six years, it has been debated whether HFCs should be phased down following the Montreal Protocol. The proposed phase-down is shown in black for the developed and developing countries in Figure 4. In the meetings of the parties in Dubai in 2015 a consensus was reached that a HFC phase-down should be under the Montreal Protocol regime. The detailed plans and agreements are expected to be finalized in 2016. This is significant progress and a strong signal to the industry to develop low GWP products.

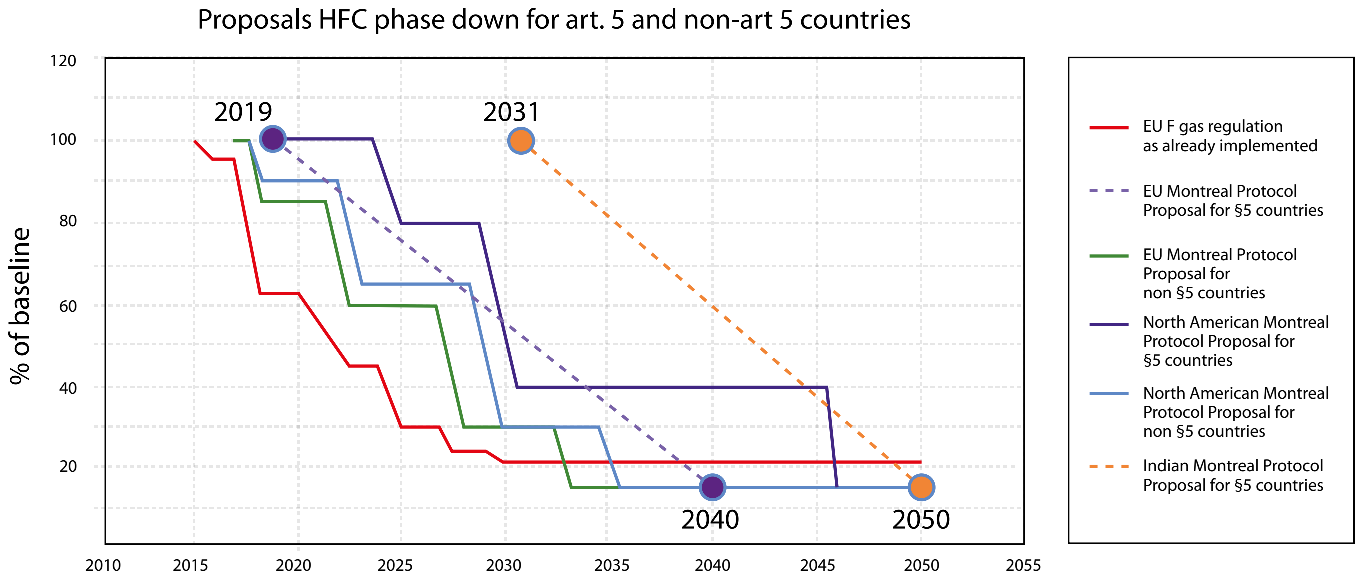


Figure 4: Refrigerant regulation timeline

In North America, the USEPA has the authority, through the Clean Air Act, to evaluate and regulate substitutes for CFC and HCFC refrigerants. In 2015, EPA launched a list of HFC refrigerants commonly used in commercial refrigeration that will no longer be accepted from specific dates; the details can be found in Annex 3. Refrigerants R404A and R507A will be targeted as early as July 2016. EPA has also given approval for three hydrocarbons; R-290, R-600, and R441A, as well as HFC-32. For mobile air conditioning the use of HFO-1234yf is allowed and millions of cars are already using it.

In Europe the F-gas regulation was implemented in 2015. Quota allocations have been made and the first phase-down step will be accomplished in 2016 with quotas reduced by 7% . Several refrigerant producers have announced price increases of 10-20 % of HFCs from January 2016. The red line on the chart shows the phase-down steps. The import of pre-charged units is not taken into account in this quota, estimated to be 11% extra, as well as the retrofit of R22 systems. The real baseline is therefore in fact higher than shown and that will create extra pressure on quotas from 2017 where the import of pre-charged units has to be absorbed in the prescribed quota. By not taking pre-charged units into account, by 2018 the quota falls to 63 percent of current usage, which will be a tremendous challenge for the industry. The final target of 21 % of today's usage is planned by 2030. In addition to quota allocation, the phase-down is managed by specific sectorial bans on high GWP HFCs. Besides the phase-down and phase-out mechanisms already discussed, governments are applying other measures for reducing high GWP refrigerants.

Further to the F-gas regulation, national tax schemes on HFCs are also used as a tool in order to reduce the impact of refrigerants on the environment; Spain, Denmark, Norway and Sweden have imposed taxes on HFCs. Additionally, national incentives in the form of subsidies on low GWP refrigerants are currently incorporated in Germany, Canada and many other countries.

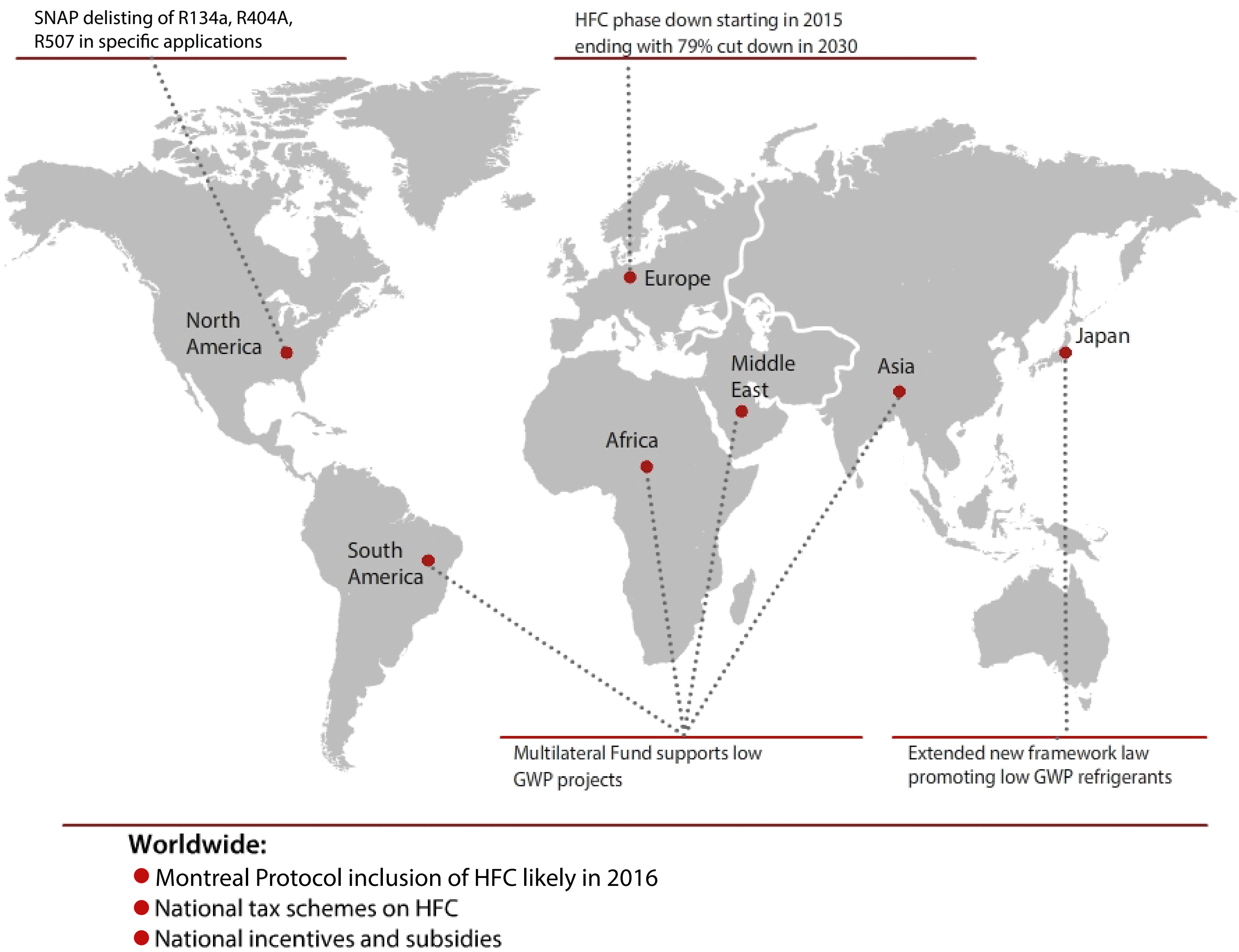
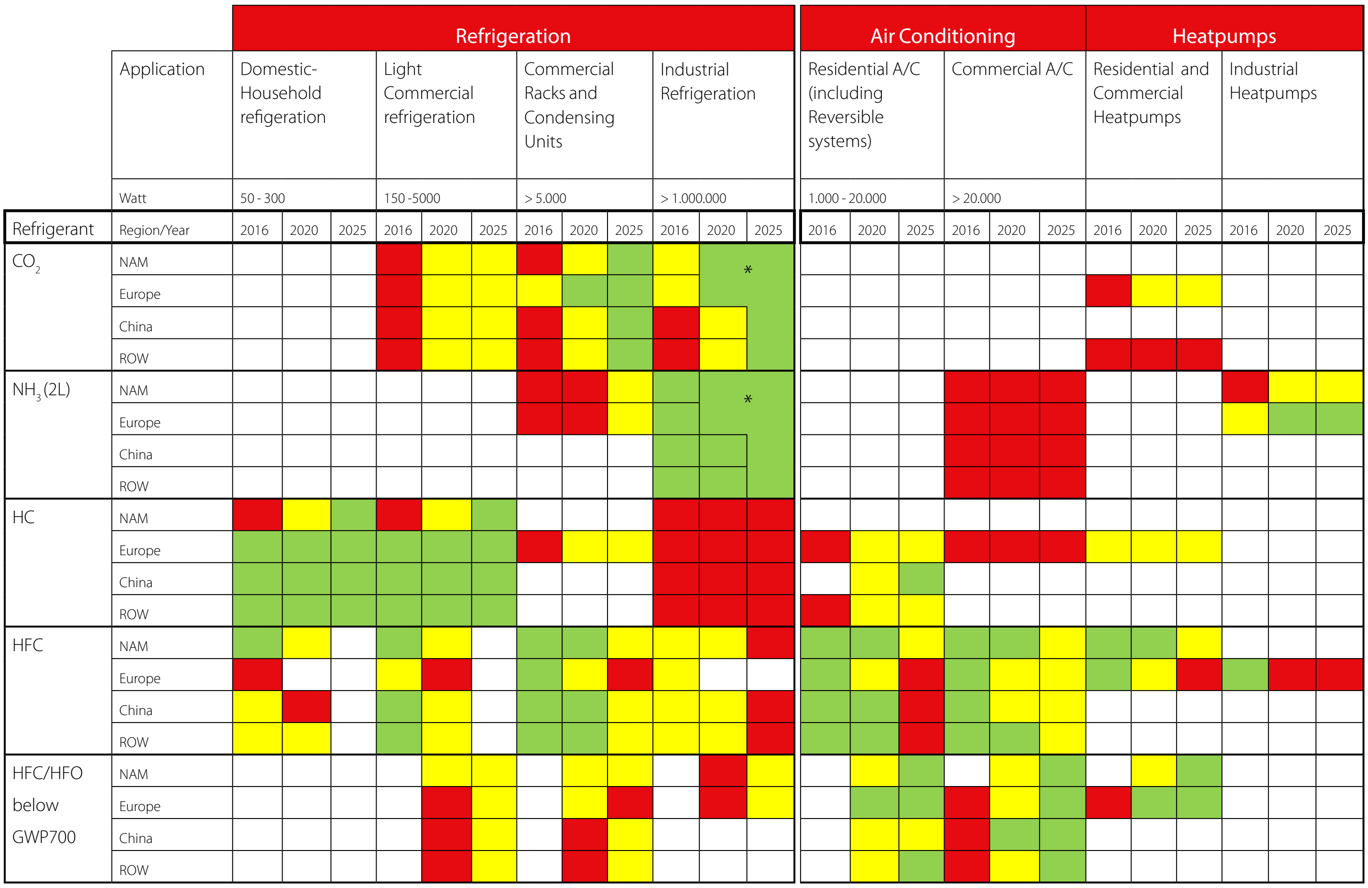


Figure 5: Global overview of refrigerant regulations

The Outlook

Our sustainability triangle tells us that there is no doubt that the environment will continue to play a very important role when defining the development and the usage of refrigerants. System manufacturers and users require long-term solutions that are environmentally benign, safe and affordable. Looking at the different alternatives, everything points to lower GWP solutions. Natural refrigerants are, by definition, low GWP solutions and they will become the preferred choice whenever possible. Safety will still be an important factor in regulating the usage of certain refrigerants. The trend clearly shows a growing acceptance of mildly flammable, A2L, refrigerants, especially now that they have been acknowledged by the new ISO standards. Also highly flammable, A3, refrigerants are increasingly used in smaller systems.

Our international group of experts within Danfoss has made a projection on the refrigerant outlook within the main sectors and regions. This outlook is summarized in the table below. CO2 is a widely used refrigerant in industrial refrigeration and commercial racks and we believe that this trend, which started in Europe, will extend to the rest of the world. Regarding the use of ammonia, we foresee that it will continue to be a very well accepted refrigerant particularly in



*Ammonia/CO_2 cascades will dominate industrial refrigeration

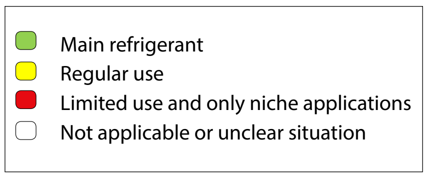


Table 1: Global trends in refrigeration and air conditioning (Status per 2014)

Industrial Refrigeration, however, its toxicity means that safety measures will also have to be considered. It is very likely that in the future a solution using both CO2 and ammonia will be used. The outlook also acknowledges that hydrocarbons, which are very efficient refrigerants, will play an important role in low charge systems around the globe. Regarding the use of HFCs, we believe that they will not disappear, but those being used will have a much lower GWP. We project HFCs will begin moving towards more environmentally friendly, but mildly flammable, versions. When dealing with mildly flammable refrigerants safety has to be addressed as a key parameter.

In 2015 two important initiatives were launched, the Global Refrigerant Management Initiative (GRMI) and the Refrigerants Driver License (RDL). Both initiatives aim at developing the service sector to encourage the competent and safe servicing and installation of systems. These initiatives address the main barriers that currently inhibit the mass introduction of low GWP refrigerants. Low GWP refrigerants will unavoidably challenge our current perception of what can be used in certain applications but will also drive innovation in system thinking and design.

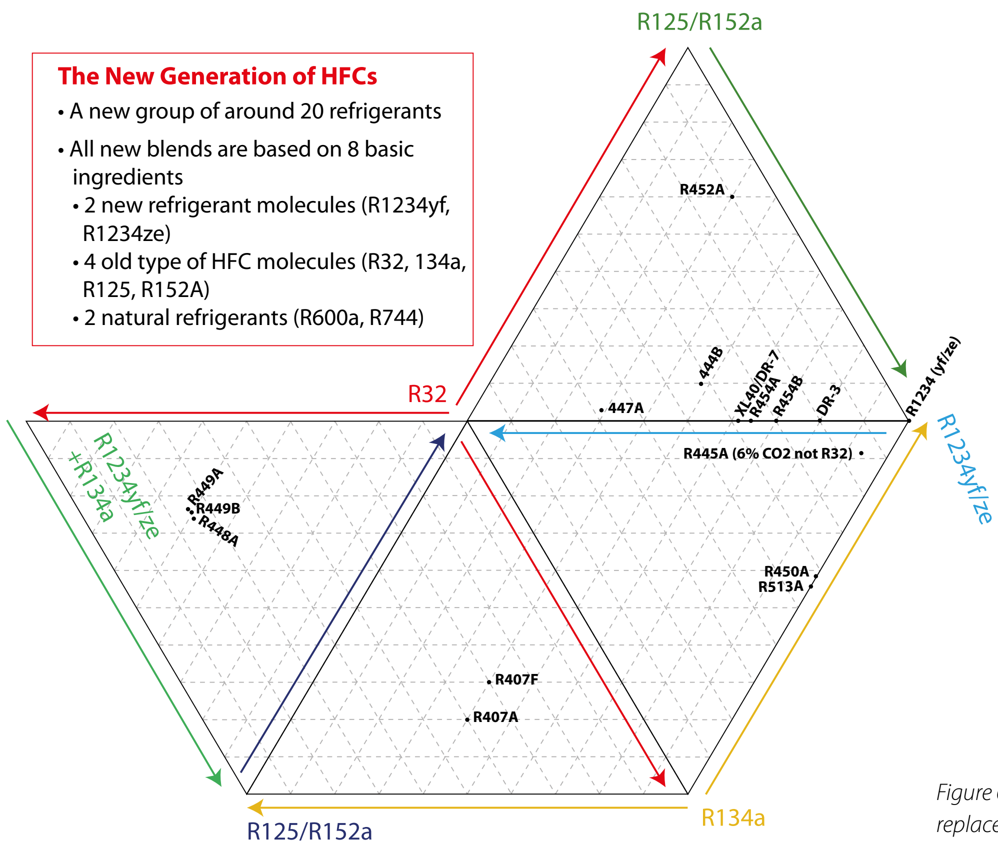


Figure 6: Refrigerant blends proposed to replace R22, R404A, and R407C

Refrigerant Options

Facing regulatory pressures to eliminate refrigerants with high GWP, many alternatives are being proposed to replace the current high GWP HFCs.
To date, to the focus has been on new unsaturated fluoro-chemical molecules, especially R1234yf, R1234ze and R1233zd, also known as HFOs.
Most of the proposed refrigerants are blends. The blends are composed of R1234yf and/or R1234ze with already established HFCs and HCs. As seen in Figure 6, the many proposed blends are similar in composition, with the differences being mainly based on which R1234 type is used and the exact refrigerant to be replaced.

There is, however, a tradeoff between lower GWP and flammability. As seen on the Figure 7, for most of the popular refrigerants there are no simple low GWP drop-in solutions. When low GWP substitutes are chosen flammability needs to be considered. The flammability seems to be linked to the capacity of the refrigerants; higher capacity comes with a higher flammability, while lower capacity refrigerants like the HCFC R123 have non-flammable substitutes.

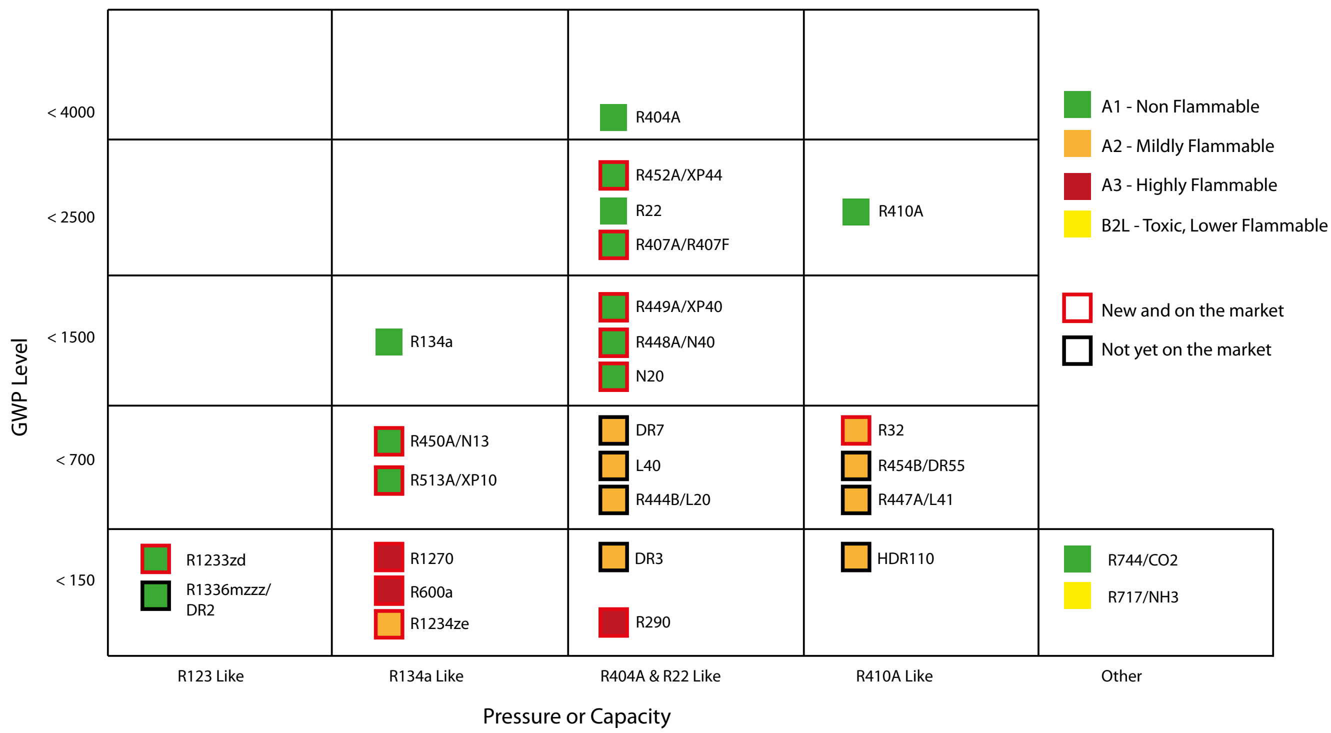


Figure 7: Carbon Chain Based Refrigerants (HCs, HFCs, HCFCs)

Paving the way

– Standardisation and risk assessment

All refrigerants are safe if standards are followed. The big question is always: are you are able to follow the standards?

In order to deal with standards, it is important to have a good understanding of their scope and structure. There are different types of standards, including international, regional and national standards, which are usually all interconnected. International standards are reflected in the national and regional standards that are adopted according to the specific circumstances of the country or region.

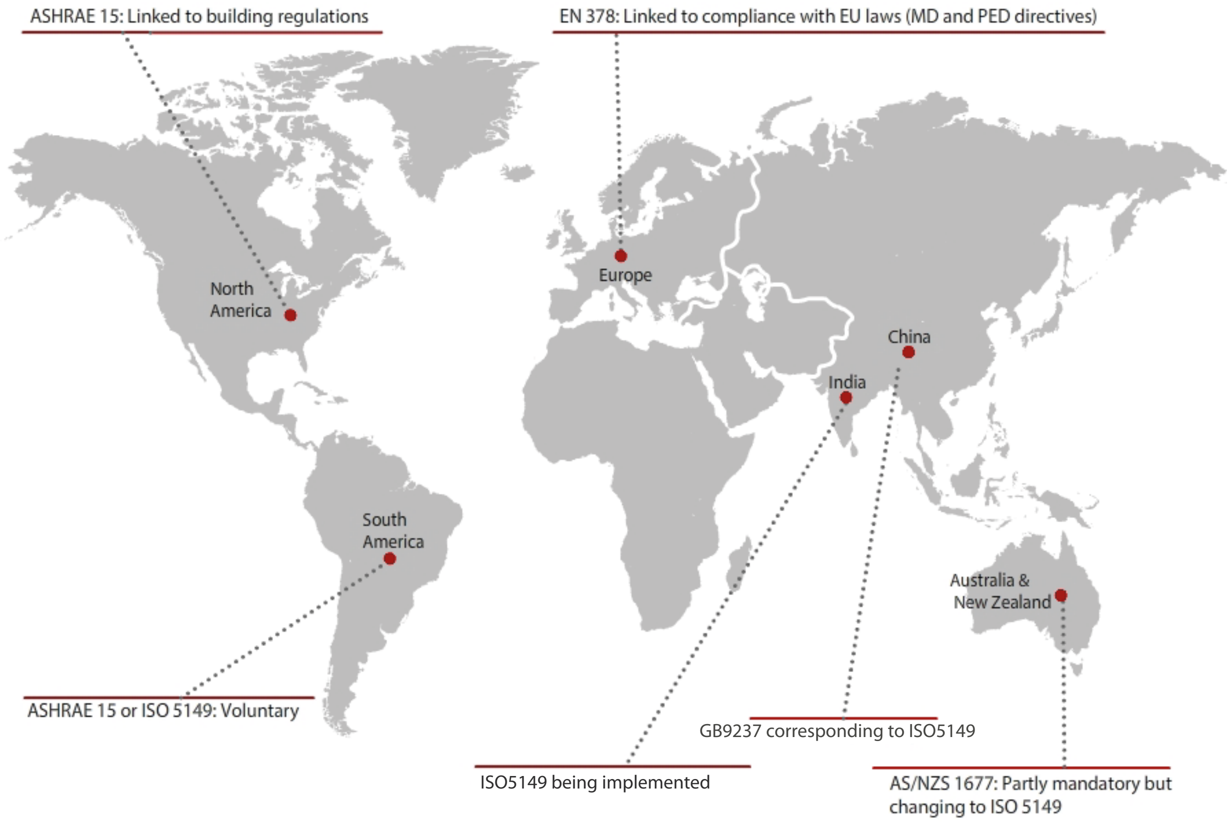


Figure 8: Global overview of Standards

Standards ensure common practice, technological alignment, and legal conformity, the last point being very important from the industries' point of view since it reduces risk and provides legal assurance when new products are developed. Danfoss participates in the standardization task-forces that contribute to the development of important safety standards such as ISO 5149 and EN378.

In the graphic below refrigerants are divided into classes depending on toxicity and flammability. A1 refrigerants are also called safety refrigerants as they eliminate flame propagation and have very low toxicity. On the other end of the scale, with high flammability and high toxicity, no refrigerants are available. Hydrocarbons are characterized by low toxicity and high flammability; special precautions have to be taken when dealing with these.

Ammonia, on the other hand, has a high toxicity and low flammability. Ammonia is widely used, especially in industrial refrigeration, and is a very efficient and effective refrigerant.

Increasing Toxicity

Increasing Flammability

	Lower Toxicity	Higher Toxicity
No flame Propagation	A1: CFC, HCFC, most HFCs	B1: Seldom used
Lower Flammability	A2L: Most HFOs, R32	B2L: Ammonia
Flammable	A2: R152	B2: Seldom used
Higher Flammability	A3: Hydrocarbons	B3: no refrigerants

Figure 9: Refrigerant classes

The new group A2L is a classification of refrigerants with a low flammability. The flame propagation speed is low and often these refrigerants are not able to sustain a flame once ignited. These refrigerants are expected to play a significant role in the future, moving away from the old high GWP HFCs.

Figure 10 shows how refrigerant standards are interconnected with safety standards;.ASHRAE 34, for example, has been used in ISO 817 in creating the refrigeration classifications. These classifications are used in safety standards such as ISO 5149 and the European safety standard EN 378 .

When evaluating refrigerants, risk awareness is always a crucial parameter. We should always ask ourselves "What level of risk is acceptable?" Before answering this question it is important to be aware of the difference between perceived and actual risk. It is important to note that the perceived risk of the new refrigerant tends to be seen as higher than the actual risk. As industry competence and user experience increase, we will see a reduction in the perceived risk of using a refrigerant. This can be compared to the perceived risk of travelling by air compared to driving a car. Driving in a car is considered safer while flying is normally perceived as more dangerous, whereas the actual risk is lower.

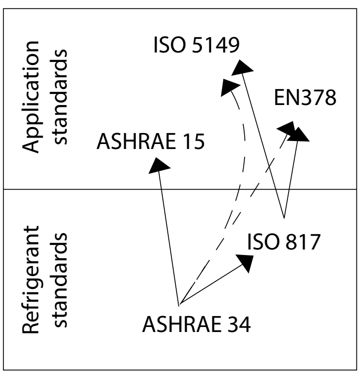


Figure 10: Refrigeration and Application Standards

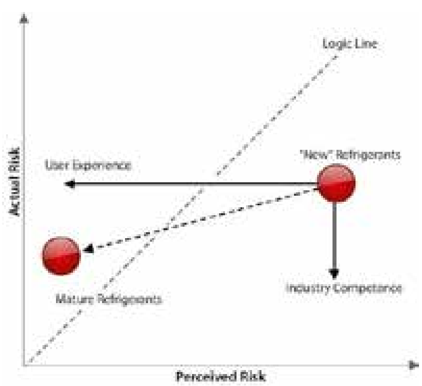


Figure 11: Perceived and Actual Risk

Before shifting to a new refrigerant with a higher flammability a very comprehensive process has to be followed. For more than a decade Danfoss has been developing products with hydrocarbons. This development process has been fine-tuned by using our application experience and knowledge of current standards and legislation to establish scenarios. By performing risk assessments we can conclude on the probability of postulated scenarios, the results of which can be used for the development of internal standards to regulate product activities with flammable refrigerants. The next step is to consult with the insurance providers and obtain approval for the new refrigerant. Finally upper management approves the refrigerant, and subsequently implements the results through the relevant product manager. As a result of continuously developing refrigerants scenarios, Danfoss has relaxed its own internal standard on flammable refrigerants. Today we offer a comprehensive program of controls for flammable refrigerants globally.

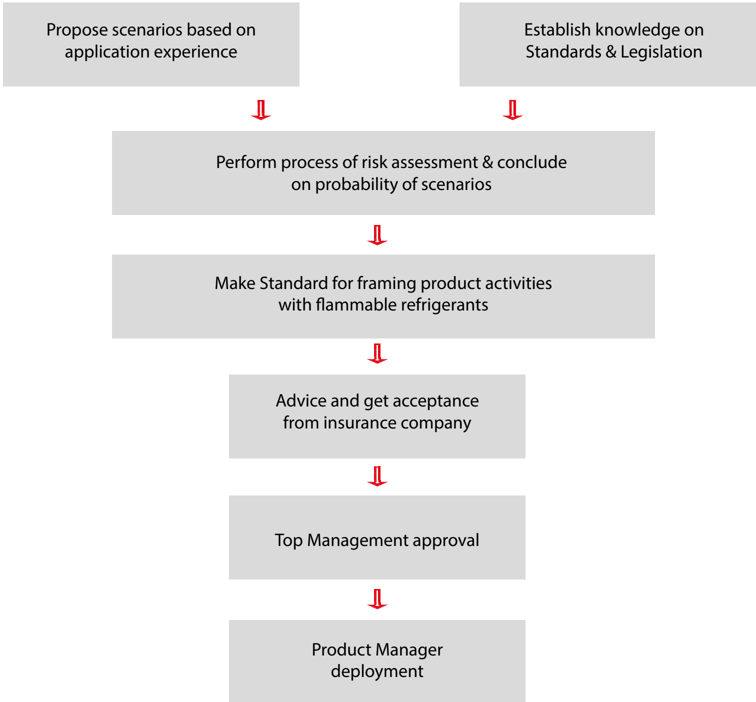


Figure 12: Danfoss' approval process

Conclusions

Refrigerants are a necessity in today's world, however they also have a great impact on the world to come. As some of yesterday's solutions have proven to bear consequences for tomorrow's environment, it is imperative that the industry looks ahead to find future proof-solutions to current challenges. To do so effectively will require a solid working partnership with a company that not only possesses a dynamic history and a comprehensive knowledge of the current standards, legislations, and new technologies, but also maintains an eye on the future in terms of safety and environmental responsibility. Danfoss offers that perfect partnership. With over eighty years of experience combined with our willingness to accept and meet the challenges of the future, we are an industry leader that is poised to offer our partners solutions they can rely on. Danfoss is ready to work with you in defining and implementing the best alternative for your applications, and together we can conquer today's challenges while addressing the needs of tomorrow.

Annex 1.

Legislation and regulation

Montreal Protocol

The latest modification of the Montreal Protocol was made in 2007. The parts most relevant to the HVACR industry are the control measures set up for the HCFCs. See table below.

Annex C – Group I: HCFCs (consumption)

Non-Article 5(1) Parties: Consumption (Developed Countries)		Article 5(1) Parties: Consumption (Developing Countries)	
Base level:	1989 HCFC consumption + 2.8 per cent of 1989 CFC consumption	Base level:	Average 2009–10
Freeze:	1996	Freeze:	January 1, 2013
35 % reduction	January 1, 2004	10 % reduction	January 1, 2015
75 % reduction	January 1, 2010	35 % reduction	January 1, 2020
90 % reduction	January 1, 2015	67.5 % reduction	January 1, 2025
99.5 % reduction	January 1, 2020, and thereafter, consumption restricted to the servicing of refrigeration and airconditioning equipment existing at that date.	97.5 % reduction (averaged over ten years 2030–40)	January 1, 2030, and thereafter, consumption restricted to the servicing of refrigeration and airconditioning equipment existing at that date.
100 % reduction	January 1, 2030	100 % reduction	January 1, 2040

Table 3: Annex C – Group I: HCFCs (consumption)
Source: UNEP

Since 2009, proposals to include HFC refrigerants in the protocol have been and are still being considered. One proposal was jointly submitted by Canada, Mexico and USA and has gained support by most countries. The proposal focuses on phasing down the use of HFC via the Montreal Protocol Based on experience with the refrigerant's predecessors CFC and HCFC, which were phased out under the Montreal Protocol, it simply seems most effective to use the Montreal Protocol forthe HFC phase-down. The Montreal Protocol focuses on production and consumption and has several advantages for jurisdiction of HFCs. Its historic success and expertise in controlling and eliminating ozone depleting substances means it already has an infrastructure (Multilateral Fund and technical and scientific bodies) which can offer a solid foundation, in order to quickly & effectively address HFCs. Effectively and quickly are, in this matter, the key arguments.

The discussion as to whether to have an HFC phase-down and to include it in the Montreal Protocol is still on-going, although there is opposition from several Countries. It would be an advantage for developing countries to obtain clear direction of future directives within the next couple of years, so the transition away from HCFCs will not have to be followed by a second transition towards low GWP alternatives.

MAC Directive (EU)

This directive bans the use of any refrigerant with a GWP above 150 in air conditioning systems in motor vehicles starting from:

- January 2011 for new models of existing vehicles
- January 2017 for all new vehicles

R134a, currently the most common refrigerant in MACs, has a GWP of 1410 and is thus affected by the ban as well. The directive does not cover other applications.

After the 2011 deadline dispensations have extended that deadline until January 1st 2013, and since then there has been attempts to extend the deadline even further, a discussion that is still on-going.

F-Gas Regulation (EU)

The EU F-gas regulation will take effect from 1 January 2015. The regulation implies an HFC phase-down from 2015 to 2030 by means of a quota system and sectorial bans on high GWP refrigerants. Especially R404A/R507 is under pressure and likely to be phased out of all commercial systems.

Since the regulation has just been adopted, there is still a great deal of uncertainty as to what will happen. Danfoss follows the situation closely and just like other experts we expect the use of natural refrigerants and other low GWP refrigerants to grow with intermediate solutions emerging like for instance 407A/F as substitutes for R404A; although these solutions are intermediate they are likely to be used for some years into the future. We also expect new blends to play a role yet to be seen.

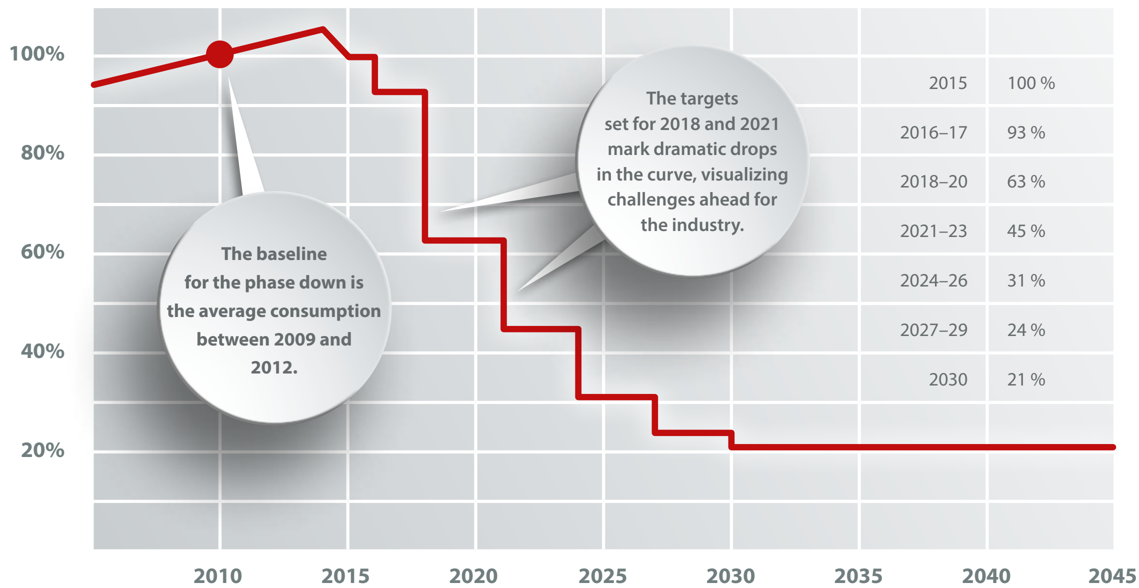


Figure 13: EU HFC Phase down schedule

What is certain, however, is the reduced availability and eventually increasing price of traditional HFCs due to the quotas is calling for changes in the refrigeration and air conditioning industry.
The phase down (figure 13) is controlled by a quota allocation system that will ensure a declining supply of HFC leading to increasing refrigerant prices. 2018 looks to be a critical year in the demand/allocation balance.

Equipment bans

The phase down schedule is complemented with bans on new equipment and bans on servicing equipment with high GWP refrigerants, as shown in figure 14. Although the service bans are far into the future they are within the expected lifespan of new equipment today. This puts pressure on the industry now to stop building R404A/507 systems .

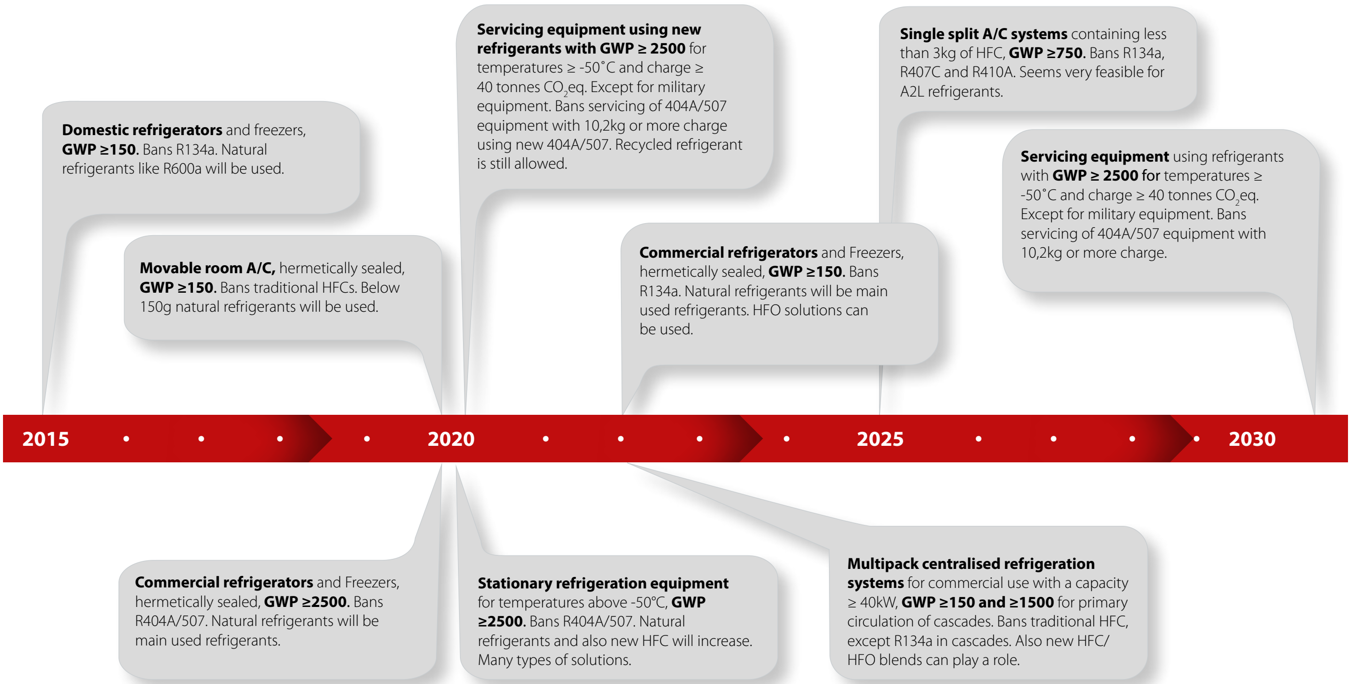


Figure 14: Bans on new equipment

SNAP (US)

The Environmental Protection Agency (EPA) in the United States has authorized hydrocarbons in selected applications through the Significant New Alternative Policy (SNAP) Program. The purpose of the SNAP program is promoting a safe and smooth transition away from ozone depleting substances.

The first rule was Rule 17, which allowed four specific hydrocarbons for use in household refrigerators and freezers and retail food refrigeration. These hydrocarbons include up to 57g R600a for the household segment and up to 150g R290 for the retail segment. Since this rule several other applications have been allowed, with charge limits similar to Rule 17, and additional rules are being proposed.

China HCFC Phase-out Management Plan (HPMP):

To fulfill the obligation towards the Montreal protocol, the Chinese authorities are supporting projects for replacing HCFCs with alternative refrigerants. The evaluation of candidates have not just focused on the ozone depletion potential (ODP), but also on GWP, safety and suitability for the application.

The recommendations from the Chinese authorities depends on the application, and among the recommendations are to use of R32 in chillers and R290 in household A/C. The recommendations are backed by the adoption of international safety standards.

Other local initiatives

A number of countries and regions have already taken steps to promote low-GWP alternatives. Such steps include a cap on the refrigerant charge (Denmark), taxation of high-GWP refrigerants (for instance in the Nordic countries and Australia), and subsidies for systems that use natural refrigerants (for instance in Germany and Quebec (Canada)).

Annex 2.

Impact of direct leakage as a function of the leakage rate

Example:

The following example can serve to illustrate the relationship between direct and indirect impacts.

Typical refrigerant plant in a medium sized supermarket:

- Store size: 1000 to 1500 m^2
- Refrigerant: R404A
- Refrigerant charge: 250 kg
- Cooling capacity: 100 kW
- Energy consumption: 252000 kWh/year
- Service life: 10 years
- GWP: 3920
- Operating time: 19 hours per day
- Recovery/recycling: 90%

CO_2 emissions from electricity production
Country A (fossil fuels): 0.8 kg CO_2 per kWh
Country B (hydro and wind power): 0.04 kg CO_2 per kWh

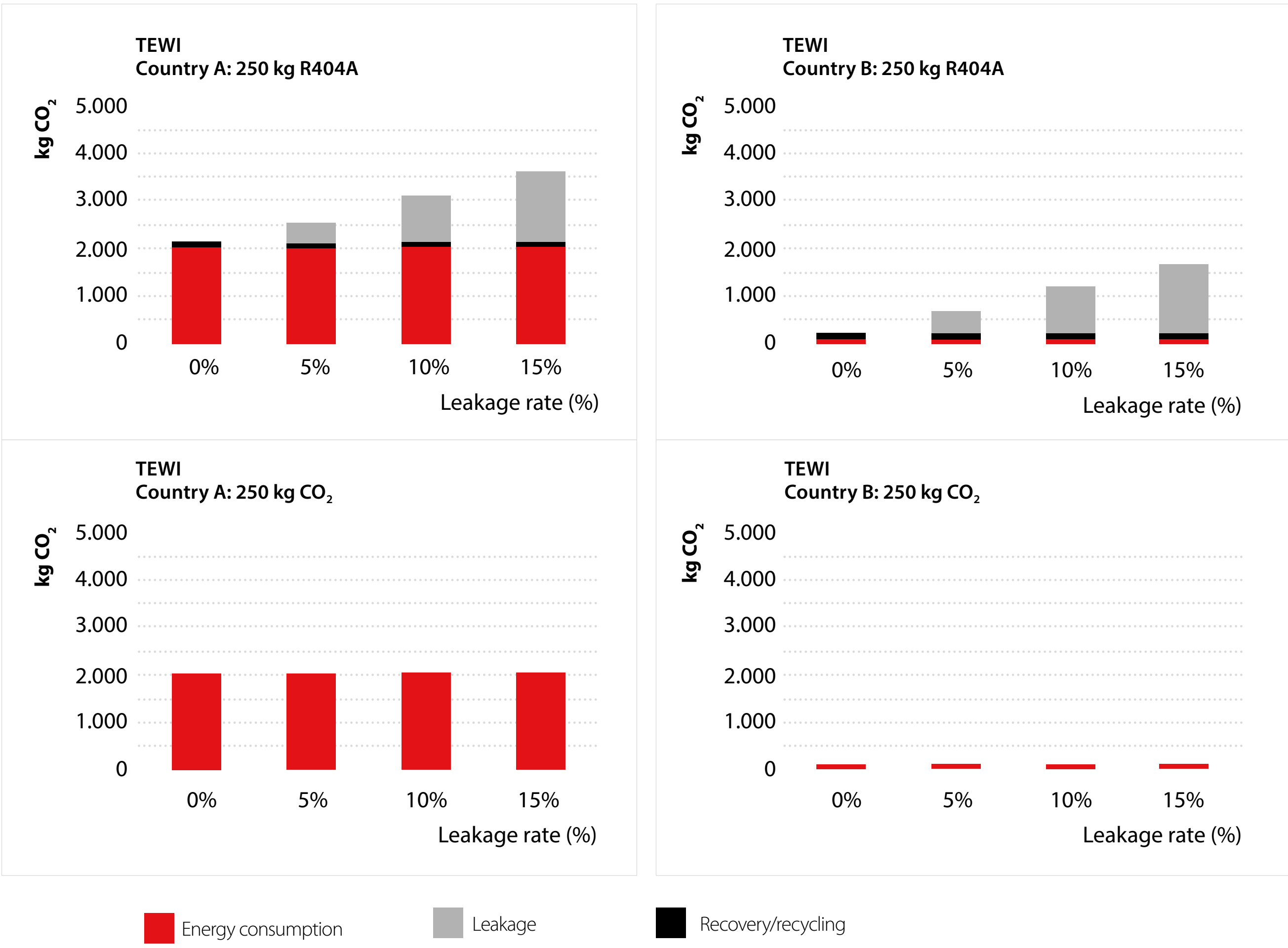


Figure 15: Relationship between the direct and indirect impacts of the refrigeration system

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Solutions for today and tomorrow

Intelligent solutions, combining natural, low GWP refrigerants and high energy efficiency, are the road to sustainable refrigeration and air conditioning. Danfoss takes a proactive approach to further the development and use of low GWP refrigerants to help abate global warming and to ensure the competitiveness of the industry.

Danfoss invests in development of products for low GWP refrigerants, both natural and synthetic to fulfil customers' needs for practical, safe and energy efficient solutions. Our product portfolio already offers a full programme of control components for CO_2, ammonia and hydrocarbons. The Danfoss product range is constantly developed to offer state-of-the-art energy efficiency in every component, from compressors to heat exchangers and everything in between.

Obtaining sustainable solutions is a fine balance between affordability, safety and environmental concerns. Based on our long-standing, sustainable mindset and our dedication to pioneering new technologies, we consciously pursue new developments aimed to he sustainable balance.

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